On an 8 km- altitude cloud and precipitation radar echo peak observed during EPIC

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1. Introduction

The NOAA Research Vessel Ronald H. Brown (RHB) was located at approximately 10 N and 95 W from September 10-31, 2001, focusing on studies of deep convection in the eastern Pacific ITCZ. A vertically pointing cloud radar (Ka-band, 8.66 mm wavelength) was present . Although cloud radars are not normally appied within heavily-raining regions, they are useful for elucidating the cloudiness strucutre. Uncertainty in the echo values from attenuation by rain is mitigated by the large (80%) percentage of data from EPIC not affected by precipitation below the melting level, and by a high radar sensitivity (-40 dBZ at 10 km, or -34 dBZ at 15 km, without attenuation) that preserves the data's utility for all but the most strongly precipitating of conditions.

Coincident precipitation radar data evaluates the vertical structure of the precipitation and can provide statistics for a larger spatial area than is sampled by the cloud radar.

This poster presents the cloud and precipitation vertical structure observed during EPIC as a function of time of day, easterly wave phase, and "disturbed" versus "undisturbed" periods. An unusual observation is a cloudiness and precipitation peak at 8 km. A peak at this altitude has not been previously documented, and is not in evidence within precipitation radar data from the TEPPS experiment that occurred at approximately 125 W and 6-8N. A hypothesis for the existence of the peak is presented, but further work is required to fully understand the presented observations.

2. Experiment-mean Statistics

As shown in Fig. 1, a maximum in cloud radar echo frequencies occurs between 1-2 km, 5-6 km, 8 km, and approximately 11-12 km. These peaks coincide with maxima within a frequency distribution of stable layers from all of the EPIC soundings (Fig. 2).

The 1-2 km peak can be explained as boundary-layer cloudiness and rain. The 11-12 km peak coincides with the level of maximum wind divergence, shown in Fig. 3a from precipitation radar data, and with the mean sounding lapse rate minimum (not shown). The 5-6 km peak occurs slightly above the melting/freezing level and is discussed by Johnson et al. (1999) and others. The 8 km peak, not previously documented, coincides with the level of maximum vertical velocity, as denoted by the regression of the divergence upon the precipitation given within Fig. 3b.
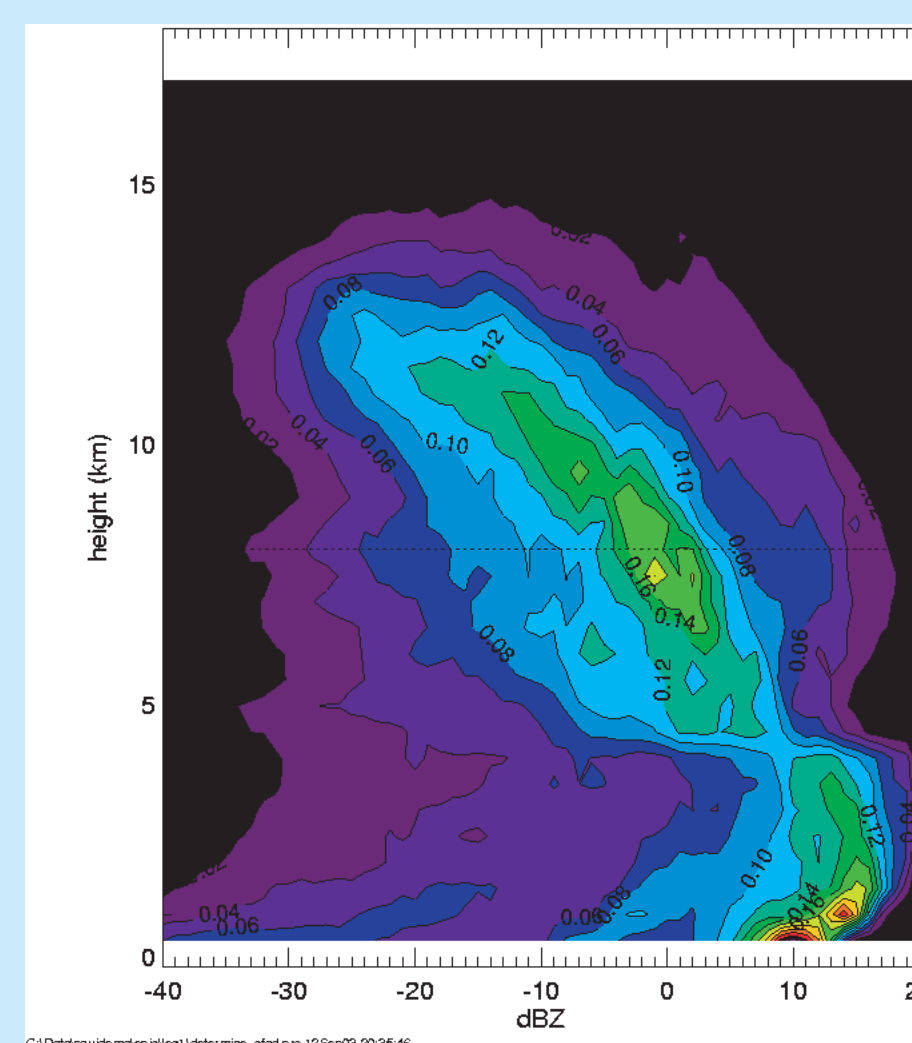
Fig. 1: A contoured frequency by altitude diagram of all the cloud radar data collected during EPIC.
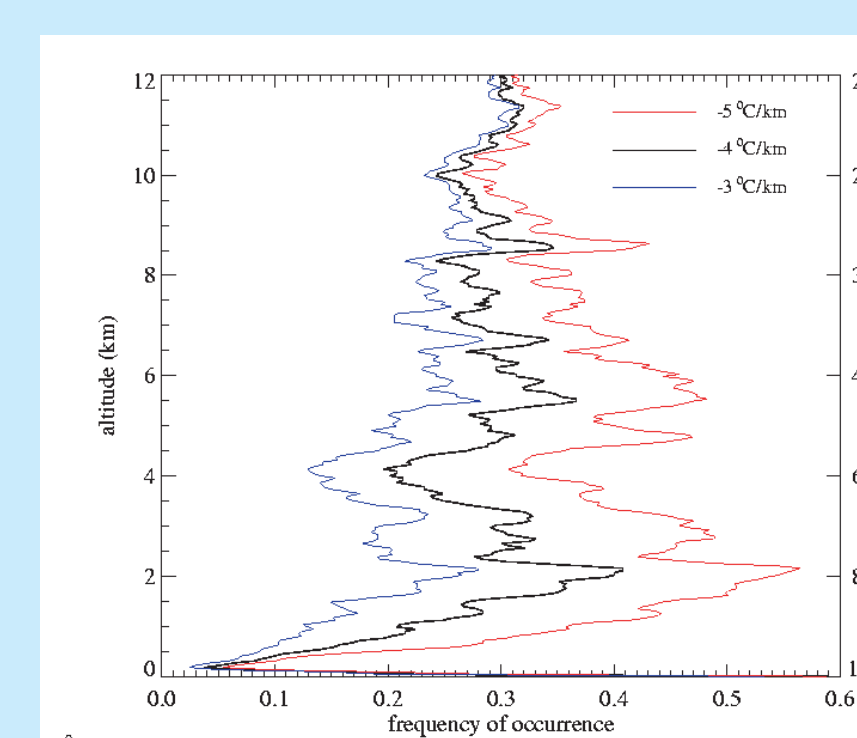
Fig. 2: A frequency distribution of stable layers within all of the EPIC soundings (107 total).
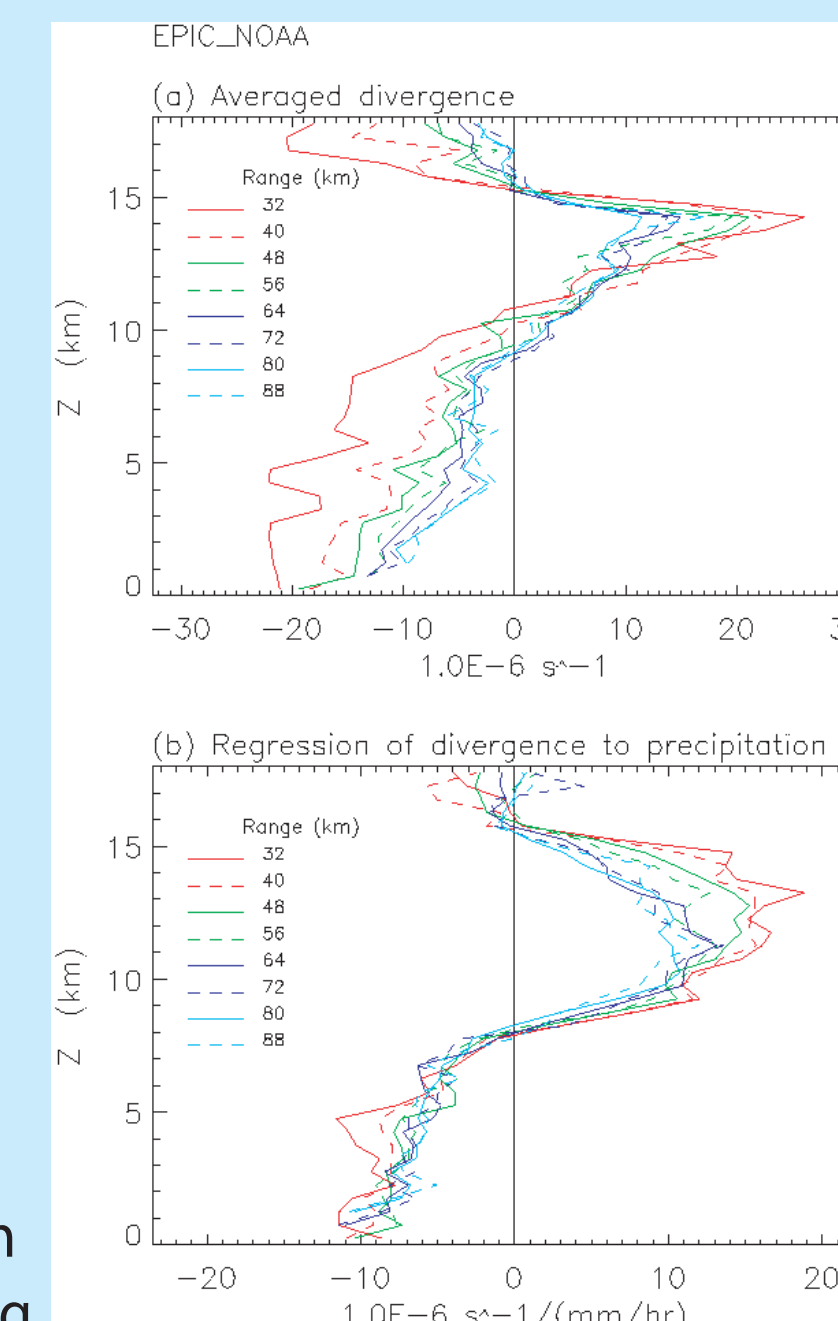
Fig. 3: The divergence profile as calculated from the precipitation radar data for several sampling areas (top panel) and the regression of the divergence upon precipitation (bottom panel)

3. Diurnal Cycle

The diurnal cycle for the cloud radar and precipitation radar echos shows that the 8 km peak is present during most of the day, with the exception of 18 or 21 local time, and that the peak is particularly pronounced between midnite and noon. The precipitation maximum occurs at approximately 3 am, and the 11-12 km convective outflow peak in the cloud radar echos occurs at approximately 9 am,. While the precipitation radar suggests two maxima at 8 km, one at 3 am and one at 12 am, the cloud radar diurnal cycle only shows one broad maximum occurring at 6 am.

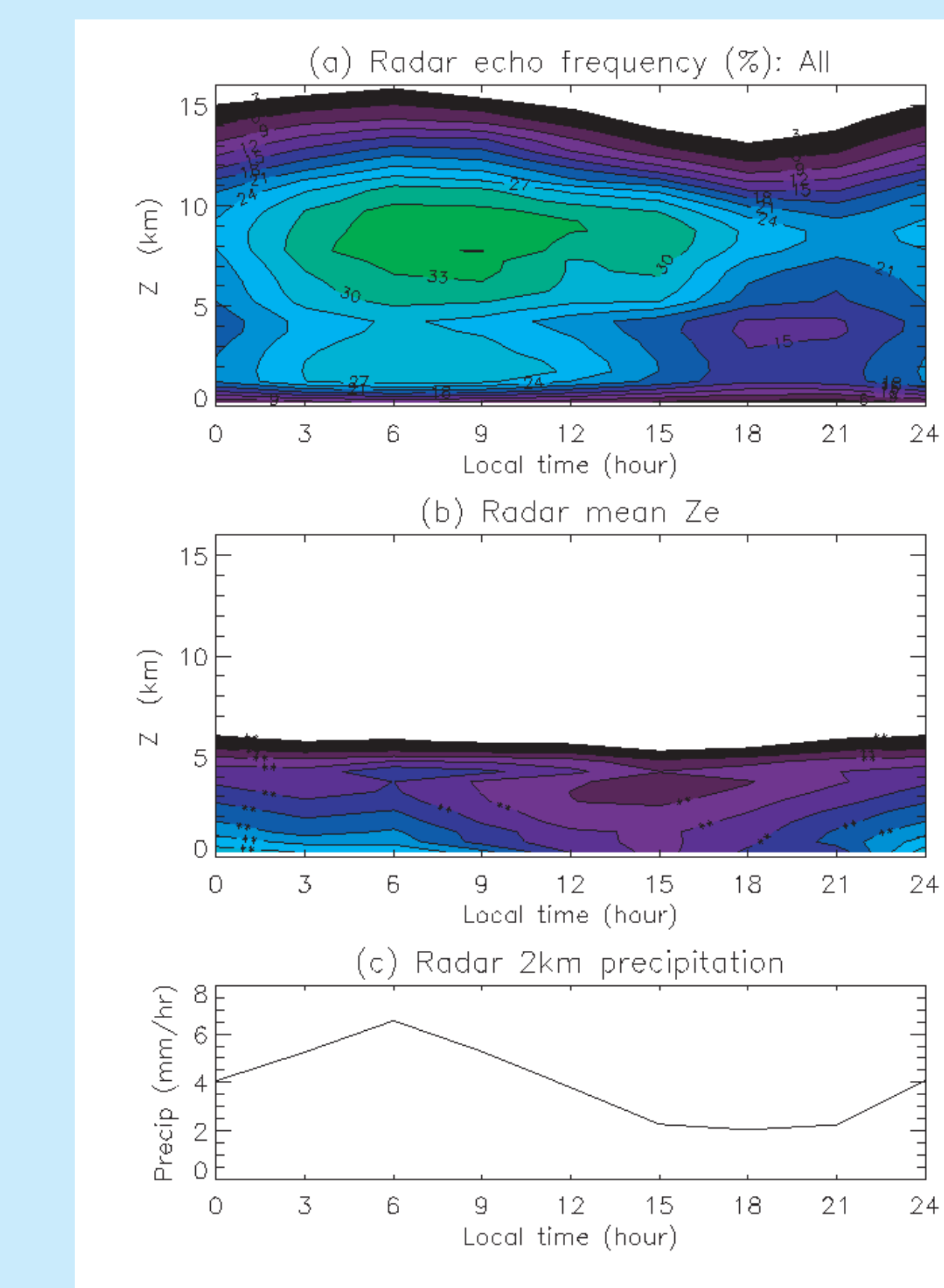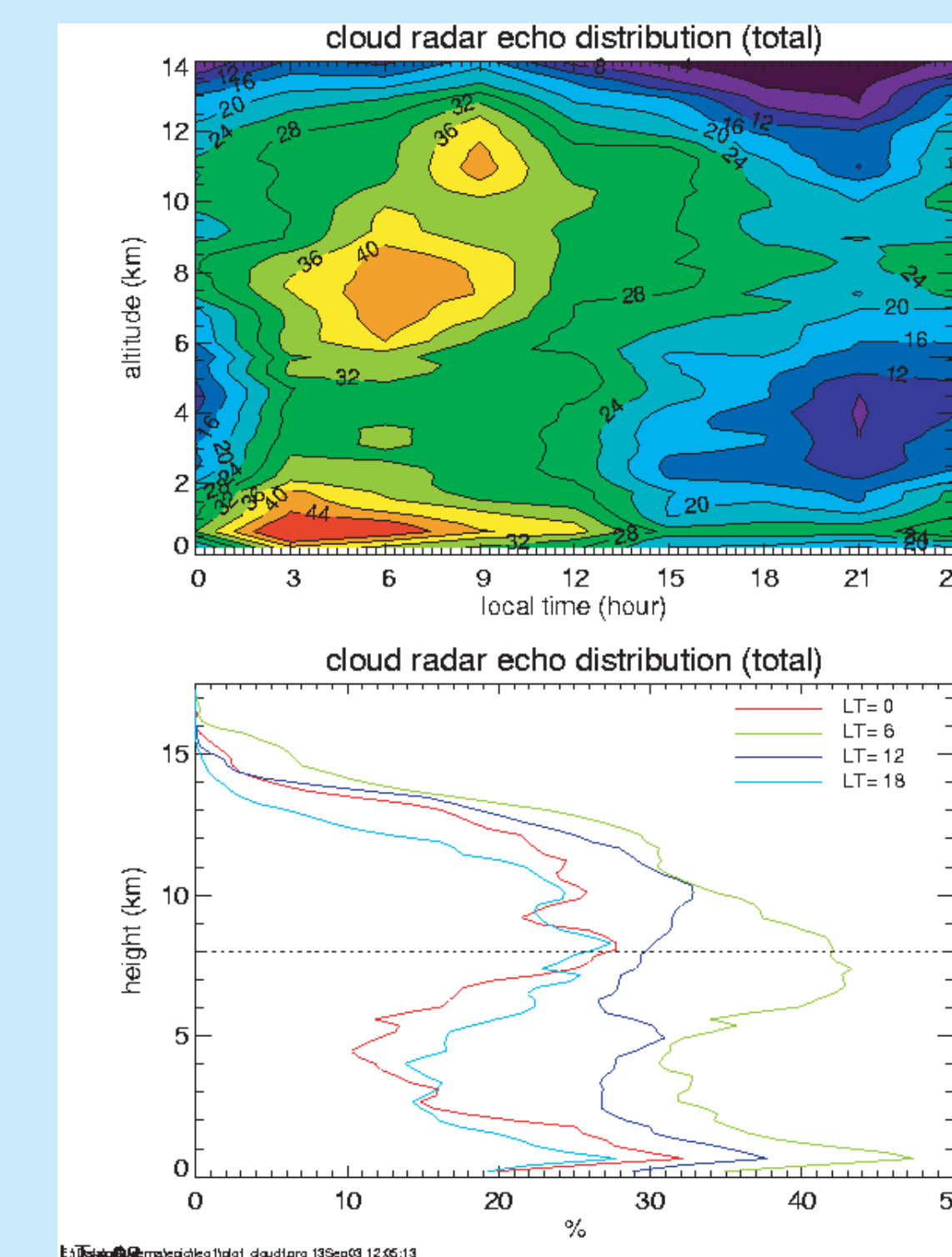Fig. 4. The diurnal cycle, from all of the EPIC cloud radar data.

Fig. 5: The diurnal cycle, for all precipitation radar echos exceeding 0 dBZ (top of right and left panels), precipitation-radar mean reflectivity (left panel, b), precipitation rate at 2 km (left panel, c), and contoured frequency by altitude diagram by time of day (right panel, bottom).
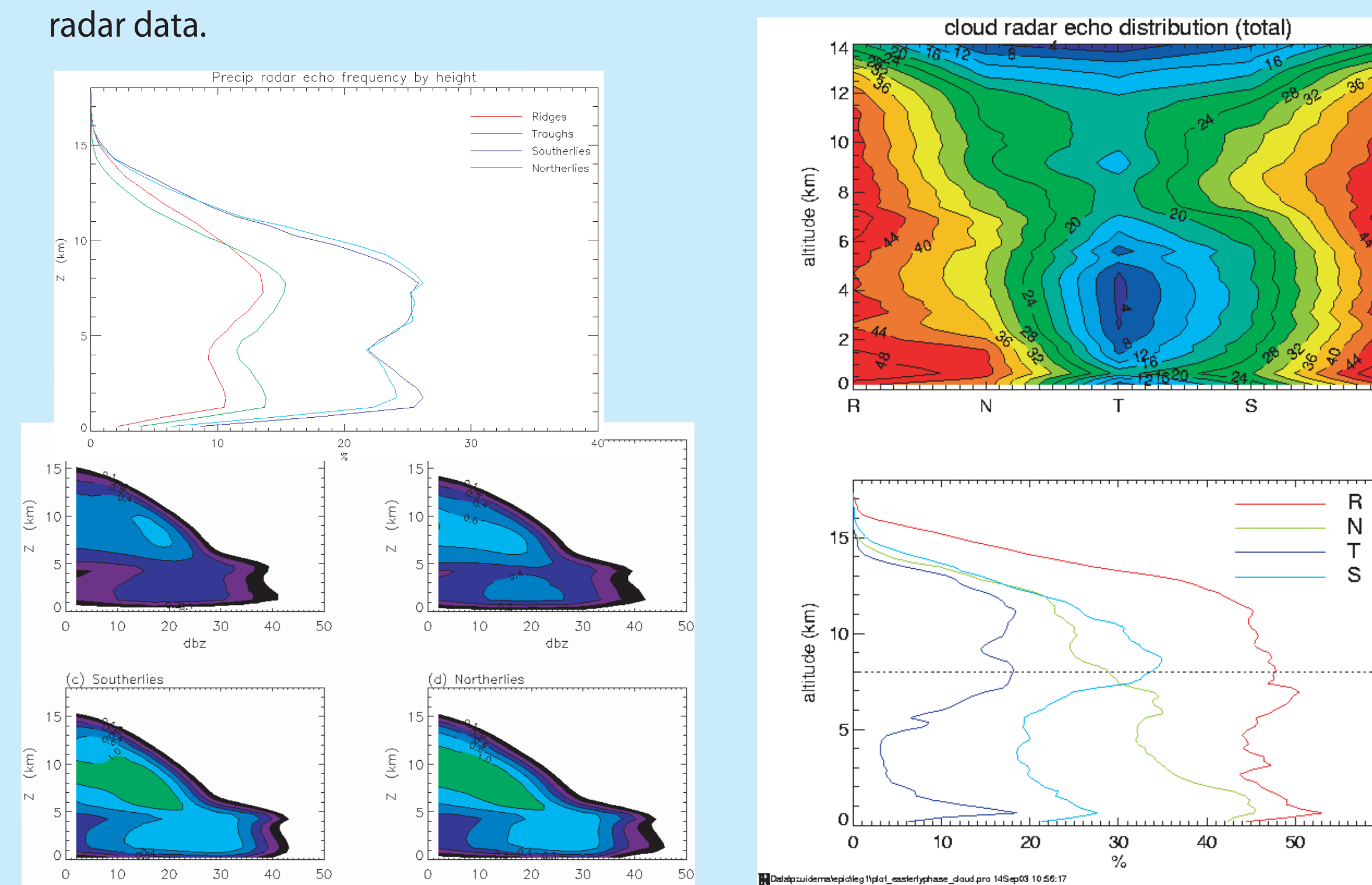
4. "no-rain" versus "heavy rain"

Cloud radar from vertical scans containing no precipitation below 4.5 km is examined to remove concerns about attenuation. The diurnal pattern is similar to that shown in Fig. 4. but no longer shows an 8 km peak in the afternoon.

The precipitation radar data is composited into "disturbed" and "undisturbed" times, based on the rainfall rate, and diurnal cycles constructed. The 8 km relative maxima for the "undisturbed" times occur about 3 hours after the relative maxima for the "disturbed" times.
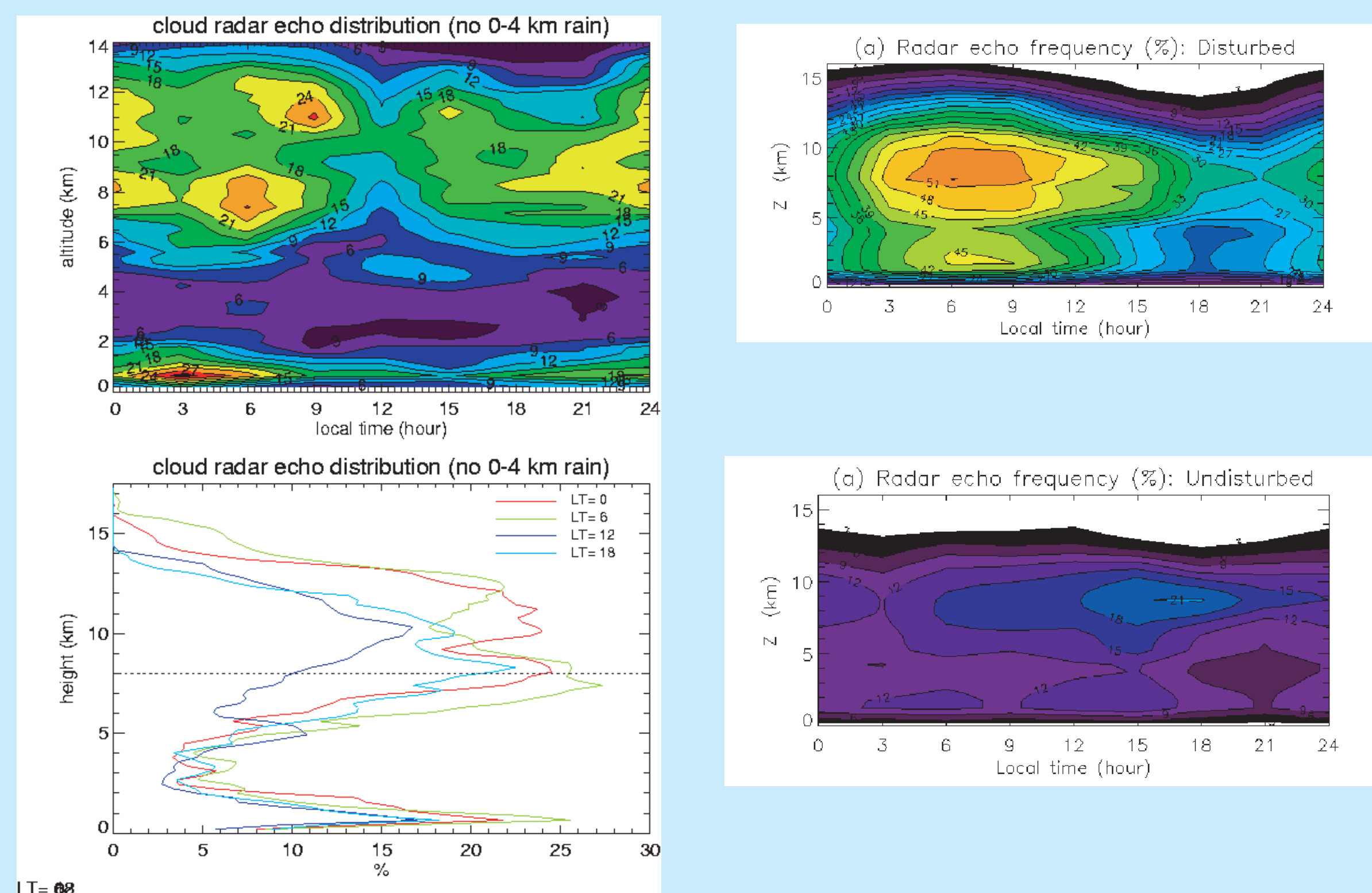
5. Easterly Wave Composite

Both the precipitation and cloud radar data are composited according to the phase of three easterly waves that swept through the experiment site, using the criteria outlined in Petersen et al., (2002). Within the cloud radar data, a slight preference of the 8 km peak is seen for the trough and southerly phases. This is less obvious within the precipitation radar data.

6. Hypothesis (and Future Work)

The existence of an 8 km peak is puzzling. At 8 km the mean temperature is -18 C and the atmosphere is still buoyant for surface parcels. Within previous modeling work (Zuidema, 1998), however, the level is a preferred detrainment level for surface parcels experiencing only liquid water condensation and no ice deposition (figure below). Although it is generally more realistic to include ice deposition above the freezing level, conditions during EPIC may have been favorable for lofting liquid to high altitudes. Such an explanation would help explain why a peak at 8 km was observed during EPIC, but not during other tropical ocean field experiments. In the words of one well-seasoned participant, EPIC was "the rainiest field experiment I have ever been on" (C. Fairall, pers. comm.) , suggesting the unique conditions of the experiment. As documented by Petersen et al., 8 km is also an altitude of strong wind shear. The strong wind shear may contribute to mid-level outflow that is then perceived as a high cloud fraction at that altitude. Further work is required to solidy this hypothesis.
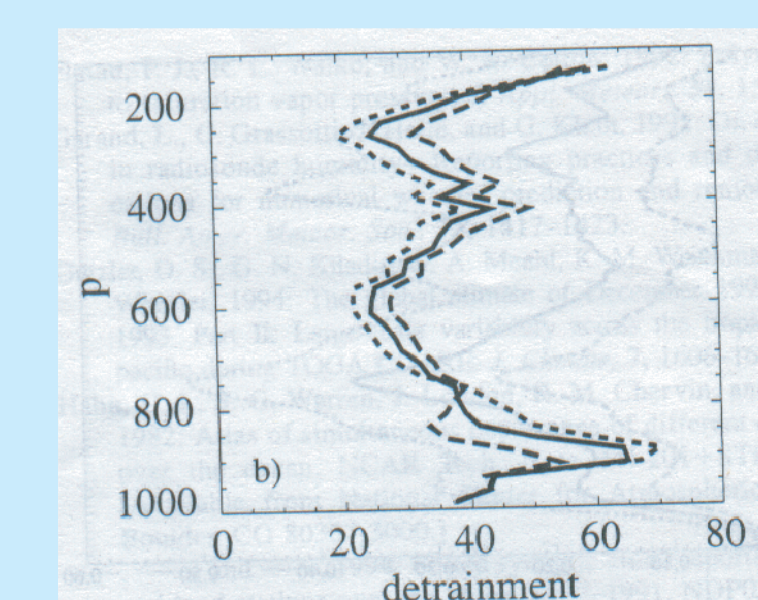
Fig. 6: Histogram of outflow levels from the Raymond-Blyth (1992) model of a total ensemble of diluted parcels from the Kapingamarangi TOGA-COARE soundings, assuming liquid water condensation only. Reproduced from Zuidema, 1998.

References:
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Petersen, W. A., R. Cifelli, D. J. Boccippio, S. A. Rutledge, C. Fairall, 2002: Convection and Easterly Wave Structure observed in the Eastern Pacific Warm-Pool during EPIC-2001. J. Atmos. Sci., submitted.
Raymond, D. J. and A. M. Blyth, 1992: Extension of the stochastic mixing model to cumulonimbus clouds. J. Atmos. Sci., 49,1968-1983.
Zuidema, P., 1998: The 600-800 mb Minimum in Tropical Cloudiness observed during TOGA-COARE. J. Atmos. Sci., 55, 2220-2228.